10/518258
Rec'd PCT/PTO 16 DEC 2004

Operation of a discharge lamp

The invention relates to a method for operating a discharge lamp including two electrodes, the method comprising applying to the electrodes an alternating current (AC). The invention relates equally to an electronic circuit for operating a discharge lamp, to a software program supporting the operation of a discharge lamp, and to a lighting system comprising such a discharge lamp.

High Intensity Discharge lamps are known from the state of the art. Such discharge lamps comprise a tube containing an inert gas or vapor. Further, two electrodes protrude into the tube. For operating the lamp, a suitable alternating current is supplied to these electrodes such that an arc is established and maintained between them.

One special type of high intensity discharge lamps is the Ultra High Performance (UHP) lamp, which may employ e.g. mercury vapor and tungsten electrodes. A common electrode construction in UHP lamps consists of a tungsten rod on which a tungsten coil is positioned. UHP lamps are used for example for projection applications, in which the optical demands on the display require arc lengths in the order of 1mm. The electrodes in UHP lamps reach temperatures close to or even above the melting point of pure tungsten. These temperatures are required to allow thermal emission of electrons in case of a highly contracted high pressure mercury arc and to avoid e.g. arc jumping. If the electrodes become too hot, however, a so called "burning back" of the electrodes occurs. As a result, the gap between the electrodes is increased, reducing the performance in optical systems. Such a "burning back" is a common reason for poor lamp maintenance. Therefore, a careful design and operation of UHP lamps are necessary, in order to guarantee a well defined electrode temperature. The same requirement may equally be given for other kinds of discharge lamps.

A problem in providing the optimal temperature for the two electrodes of a discharge lamp may arise in particular, in case the two electrodes reach different

temperatures. Such a situation may also occur if two similar electrodes are employed, since these electrodes may be used asymmetrically. As a consequence, one electrode may still work under its design conditions in a proper way, while the other electrode suffers either from arc jumping since it is too cold, or from "burning back" since it is too hot.

There is a variety of factors which may lead to an asymmetry between two electrodes of a discharge lamp.

Firstly, a discharge lamp is usually employed in a reflector, which reflector may act as a cooling fin for the lamp. Depending on the mounting of the lamp in the reflector, one end of the lamp, and thus one electrode, may be cooled more than the other end with the other electrode.

Further, an increasing amount of UHP lamps is operated with a forced air cooling. This cooling is usually directed to the front end of the lamp or to the upper side of the lamp. Depending on the details of this airflow, highly different electrode temperatures can be observed.

Current UHP lamps are moreover designed to be operated in a horizontal burning position. Some applications, however, use the lamp in a tilted or even vertical position. As a result, the two electrodes receive a different heat load by the convective upwards flow of hot gas, and therefore they reach different temperatures.

During the lifetime of a discharge lamp, also the structure of the electrodes may change due to mechanical movements of parts of the electrodes, e.g. of the coil on the rod. Even in new lamps, the structure of the electrodes may vary due to tolerances. In case one of the electrodes already started to "burn back", its abilities to conduct and to emit heat change, and the process may speed up leading to an early lamp failure.

Most of these asymmetries cannot be compensated by using different electrodes, because they are unpredictable. Different electrodes further prevent a general use of the lamps and require additional care when inserting the lamp into the system in which it is employed.

It is an object of the invention to increase the performance and the lifetime of discharge lamps. It is in particular an object of the invention to provide a possibility of maintaining a temperature balance between two electrodes of a discharge

lamp.

These objects are reached according to the invention with a method for operating a discharge lamp including two electrodes, which method comprises applying to the electrodes an alternating current. It is proposed that this alternating current has a direct current component for compensating a temperature difference between the two electrodes. The direct current component is selected to this end such that a first one of the electrodes, which is expected to have a lower temperature than the second one of the electrodes, functions as anode for the direct current component, while the second electrode functions as cathode for the direct current component.

The objects of the invention are equally reached with an electronic circuit employed for operating a discharge lamp with two electrodes, which electronic circuit comprises means for realizing the proposed method. Further, the objects of the invention are reached with a software program for operating a discharge lamp with two electrodes, which software program comprises a software code realizing the proposed method when run in processing means of a driver controlling the power supply to the discharge lamp. Finally, the objects of the invention are reached with a lighting system, for instance a projection system, which comprises a discharge lamp with two electrodes and means for operating this discharge lamp according to the proposed method.

The two electrodes of the discharge lamp that is to be operated can be in particular, though not necessarily, similar electrodes.

The invention proceeds from the recognition that an electrode is heated more if it acts like an anode and is heated less if it acts like a cathode. Therefore, it is proposed to operate a discharge lamp with an alternating current which has a direct current component, the direct current component being used for balancing the temperature of the two electrodes.

It is an advantage of the invention that it allows to operate a discharge lamp such that both electrodes will run at the same temperature, which enables the setting of an optimum temperature for both electrodes. Thereby, arc jumping and a "burning back" of the electrodes can be avoided. As a result, the performance of a gas discharge lamp will be improved and its lifetime be increased for the case that the lamp operated in an asymmetric manner.

Preferred embodiments of the invention become apparent from the

dependent claims.

The desired DC component of the alternating current applied to the electrodes of the discharge lamp can be achieved in several ways.

In a first preferred embodiment of the invention, the DC component is obtained by superimposing a DC current to the standard AC lamp current.

In a second preferred embodiment of the invention, the DC component is obtained by using a different strength of the AC current for the two current directions.

In a third preferred embodiment of the invention, the DC component is obtained by changing the time during which the lamp is operated in the two current directions. While in a standard AC operation, the waveform of the alternating current has a duty cycle with two half cycles of equal length for the two current directions, the proposed adjustment thus results in an operation with a duty cycle deviating from the standard 50:50 situation.

In a fourth preferred embodiment of the invention, the DC component is obtained by adapting the energy content of one or more additional pulses employed in each half cycle of the alternating current in a way that the energy content of these additional pulses is larger in one current direction than in the other. The energy content of such additional pulses can be adapted in particular by adapting the amplitude and/or the time of the additional current pulse or pulses individually for each half-cycle.

The amount of the DC component employed for balancing the temperature lies preferably in the range of 0.1% to 50% of the total current amount.

The expected temperature situation can equally be determined in different ways.

In case the asymmetrical heating of the electrodes is expected to be basically constant during the life time of the lamp, e.g. due to a predetermined orientation of the lamp or due to the arrangement of means producing a cooling air flow, it might be sufficient to predetermine the required amount of the DC component with some sample lamps. This amount can then be set as a fixed DC component for the lamp power supply.

In case the asymmetrical heating of the electrodes is not constant during the life time of the lamp, e.g. due to changing operating conditions or due to a changing electrode structure, the temperature situation of the electrodes is advantageously

supervised individually for each lamp during its entire lifetime. The required amount of the DC component can then be determined continuously or repeatedly based on the respective temperature situation.

For determining the temperature situation in a rather simple way, the lamp burning voltage can be measured by the driver of the lamp at several times, i.e. at least twice, during one half cycle of the alternating current supplied to the lamp. If the measured voltage is slightly increasing during one half cycle, the electrode acting as a cathode in this half cycle can be assumed to be hot enough. If the voltage is decreasing or shows a sudden drop during one half cycle, in contrast, the electrode acting as a cathode in this half cycle can be assumed to be too cold. As only the respective cathode causes these voltage changes, both electrodes can be observed independently when taking into account the alternating current direction. A corresponding detection of electrodes that have to be considered to be too cold has also been described in document US 6,232,725.

The method according to the invention can further be integrated into a control loop controlling the current supply to the lamp and adjusting the DC component continuously.

Moreover, information about the adjusted DC component can be stored in a non volatile memory, e.g. only the last applied value or more extensive information like the entire lamp history. The information can comprise for example the value of the respectively employed DC component, determined temperatures or temperature differences, or determined lamp voltages. The stored information can then be used for future predictions of the required amount of the DC component.

In order to operate both electrodes always at an optimum temperature, in addition an adjustment of the average lamp power should be enabled, e.g. for the case that both electrodes are too cold or hot enough. This aspect may also be included in a provided control loop. Thereby, an arc jumping at both electrodes and a "burning back" of both electrodes in case of a balanced but non-optimum temperature can be avoided.

The operated discharge lamp can be in particular a UHP lamp, but equally any other discharge lamp.

The method according to the invention can be implemented in an electronic circuit employed for operating the discharge lamp.

The method according to the invention can be realized in particular by software, which may be implemented e.g. in a micro-controller controlling the driver of the discharge lamp.

Other objects and features of the present invention will become apparent from the following detailed description of selected embodiments of the invention considered in conjunction with the accompanying drawings, wherein

Fig. 1 shows a block diagram of a part of an embodiment of a projection system according to the invention;

Fig. 2 shows an alternating block current without a direct current component;

Fig. 3 shows an alternating block current with current pulses without a direct current component;

Fig. 4 shows an alternating block current with a superimposed direct current;

Fig. 5 shows an alternating block current with an asymmetrical duty cycle;

Fig. 6 shows an alternating block current with amplitude modulated current pulses; and

Fig. 7 shows an alternating block current with time modulated current pulses.

Figure 1 shows in form of a block diagram components of a of projection system in which an embodiment of the method according to the invention may be implemented.

The projection system comprises a UHP lamp 11 which is to be operated according to the invention. Two electrodes 12, 13 of the UHP lamp 11 are connected to this end to a controllable power supply circuit 14. The power supply circuit 14 may comprise in particular a power supply unit providing a direct current of a controllable value, and a controllable inverter transforming the provided direct current into an

alternating current I_{Lamp} desired for operating the lamp 11.

The power supply circuit 14 is controlled by a micro-controller 15. The micro-controller 15 comprises a software, which is able to control the power supply circuit 14 in a conventional manner. That is, the software causes the power supply circuit 14 to supply an alternating current I_{Lamp} to the UHP lamp 11 which is suited to establish and maintain an arc between the two electrodes 12, 13. The software is in addition able to adjust the conventionally supplied alternating current to comprise a desired direct current component.

The micro-controller 15 further comprises a non-volatile memory. In this memory, the history of the provided direct current components is stored. The micro-controller 15 receives as input information on the current lamp voltage via a voltage detector 16 detecting the respective voltage U_{Lamp} over the UHP lamp 11. Power supply circuit 14, micro-controller 15 and voltage detector 16 constitute together the driver of the UHP lamp 11.

The software of the micro-controller adjusts the direct current component of the current I_{Lamp} supplied by the power supply circuit 14 in a control loop. In this control loop, the software first evaluates information on the lamp voltage received by the voltage detector 16. The lamp burning voltage U_{Lamp} is measured by the voltage detector 16 repeatedly during each half cycle of the alternating current supplied to the lamp 11. If this voltage U_{Lamp} is determined by the software to be increasing during one half cycle, the electrode 12, 13 acting in this half cycle as a cathode is hot enough. If the voltage is determined by the software to be decreasing or to show a sudden drop during one half cycle, the electrode 12, 13 acting in this half cycle as a cathode is too cold.

Based on this evaluation, the software then adjusts its conventional control of the power supply circuit 14 and thus of the conventionally supplied alternating current. That is, in case it is determined that one electrode 12, 13 is too cold, the direct current component is increased in a sense that this electrode 12, 13 acts more as an anode than before. In case it is determined that both electrodes 12, 13 are hot enough, in contrast, the direct current component is lowered in order to approach a pure alternating current operation. Further below, four different solutions for adjusting the conventional alternating current to comprise a direct current component will be presented with reference to figures 2 to 7.

In addition, the entire average lamp power is increased in the control loop, in case it is determined that both electrodes 12, 13 are too cold. In case it is determined that both electrodes 12, 13 are hot enough, while it can be concluded from the lamp history stored in the memory of the micro-controller 15 that both electrodes do not tend to approach the critical temperature boundary, the average lamp power is lowered.

Thus, the presented system allows to operate both electrodes 12, 13 of the UHP lamp 11 always at an optimum temperature.

Figures 2 to 7 are diagrams depicting different lamp currents I_{Lamp} over time t.

Figures 2 and 3 illustrate the course of alternating currents I_{Lamp} supplied conventionally to a UHP lamp 11. Figure 2 shows a standard block current. In this block current, each duty cycle has two half cycles I, II of the same length, during which a constant current of the same amplitude but opposed polarity is provided. The half cycle I with a positive current will also be referred to as positive half cycle, and the half cycle II with a negative current will also be referred to as negative half cycle. Figure 3 shows a similar standard block current, in which an additional current pulse P1, P2 having the same polarity as the regular block current is added at the end of each half cycle I, II. The use of such a current comprising additional pulses is known for instance from document EP 0 766 906 A. As can be seen in figures 2 and 3, the conventional alternating current does not have any direct current component. Such a conventional current is also supplied by the power supply 14 of figure 1 to the UHP lamp 11, in case the micro-controller 15 determines that the both electrodes 12, 13 are currently hot enough, or that both electrodes 12, 13 are too cold and that thus only the total average power has to be increased.

Different possibilities for adjusting the direct current component of the supplied alternating current to a desired value when proceeding from one of the conventionally supplied alternating currents illustrated in figures 2 and 3 are illustrated in figures 4 to 7.

In the solution presented in figure 4, a desired direct current is simply superimposed to the provided alternating block current of figure 2. The additional direct current is provided by the power supply circuit 14 according to control signals by the

micro-controller 15. In the depicted situation, a positive direct current is superimposed to the conventional alternating current. As a result, the alternating current I_{Lamp} provided to the lamp comprises a positive direct current component DC corresponding to the superimposed direct current, as indicated in the figure. The same effect can be reached without additional means for superimposing a direct current, and thus without a change of the structure of the conventionally used power supply, by using a different current strength in both directions of the conventional alternating current.

Figure 5 proceeds equally from the standard alternating block current depicted in figure 2. In the solution presented in figure 5, a direct current component is achieved by increasing the length of the one of the half cycles of a duty cycle of the conventional alternating current and by reducing the length of the other one of the half cycles of the duty cycle. The length of the half cycles is set in the power supply circuit 14 according to control signals by the micro-controller 15. In the depicted situation, the respective positive half cycle I is longer than the respective negative half cycle II. As a result, the alternating current comprises the positive direct current component DC indicated in the figure.

Figure 6 proceeds from the standard alternating block current with additional current pulses depicted in figure 3. In the solution presented in figure 6, a direct current component is achieved by modulating the amplitude of the additional current pulses in each half cycle. The modulation of the amplitude of the additional current pulses is set in the power supply circuit 14 according to control signals by the micro-controller 15. In the depicted situation, the additional current pulse P1 in the positive half cycle I has a larger amplitude than the additional current pulse P2 in the negative half cycle II. As a result, the alternating current comprises the positive direct current component DC indicated in the figure.

Figure 7 proceeds again from the standard alternating block current with additional current pulses depicted in figure 3. In the solution presented in figure 7, a direct current component is achieved by modulating the time of the additional current pulses in each half cycle. The modulation of the time of the additional current pulses is set in the power supply circuit 14 according to control signals by the micro-controller 15. In the depicted situation, the additional current pulse P1 in the positive half cycle I has a longer duration than the additional current pulse P2 in the negative half cycle II.

As a result, the alternating current comprises the positive direct current component DC indicated in the figure.

It is to be noted that the presented embodiments of the invention constitute only selected embodiments which can be varied in many ways.